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14. ABSTRACT This report summaries our accomplishment in the area of DNA-based nanofabrication, supported by ONR grant N00014-13-1-0575. During the funding period, our research produced 21 peer-reviewed journal publications and 23 conference presentations/invited talks. Specifically, we have: (a) Studied the water adsorption on DNA origami template and its impact on DNA-mediated chemical reactions. We also extended the concept of DNA-mediated reaction to other nanoscale templates. (b) Studied the thermal and chemical stability of DNA origami template. The result shows that the DNA nanostructures can be potentially used in very harsh chemical environments. (c) Studied the effect of DNA origami template on the growth of self-assembled monolayer (SAM) structure. We developed a method to produce nanoscale patterns on SAM. (d) Studied the molecular imprinting of DNA origami structure using polymer substrates. Developed a high-resolution pattern transfer approach to pattern polymer surfaces. (e) Evaluated precursors for solution deposition of CdE (E = S, Se, and Te) semiconductors onto a DNA template. (f) Studied the wettability of graphitic carbon materials and its impact on the interaction between graphitic substrate and DNA nanostructures.					
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## **Final Technical Report**

**Principal Investigator Name: Haitao Liu**

**Organization: University of Pittsburgh**

**ONR Award Number: N000141310575**

**Award Title: DNA-Based Molecular Scale Nanofabrication**

**Reporting period: May 14, 2013 to May 15, 2015**

## **1. Scientific and Technical Objectives**

The objective of this research is to test the hypothesis that a DNA nanostructure can be used as a template for site-selective etching and deposition of inorganic materials. The specific aims are: (1) to provide a fundamental understanding of the effect of DNA on the adsorption of inorganic precursors and catalysts; (2) to develop DNA-templated reactions for the fabrication of a wide range of inorganic nanostructures with low cost, high throughput, and ultra-high resolution. In addition, we have expanded our efforts to include DNA-mediated HF etching of SiO<sub>2</sub>, DNA-mediated nanoimprinting lithography, DNA-based patterning of self-assembled monolayers (SAM), and pattern transfer using protein nanostructures.

## **2. Approach**

To achieve the specific aims, we will carry out a detailed kinetics study of DNA-mediated chemical reactions. Examples of such reactions include chemical vapor deposition (CVD) of inorganic oxide and HF etching of SiO<sub>2</sub>. These studies will be carried out in a custom-built flow reactor that offers precise control of the reaction conditions. In these reactions, the DNA mediates the reactivity by controlling the adsorption of water. The effect of DNA on the adsorption of water will be extracted from the kinetics data. Building upon these fundamental understanding, we will develop new physical and chemical approaches that will transfer the shape of a DNA template into various organic/inorganic substrates.

## **3 Concise Accomplishments**

During the funding period, our research produced **21** peer-reviewed journal publications and **23** conference presentations/invited talks. Specifically, we have:

- (a) Studied the water adsorption on DNA origami template and its impact on DNA-mediated chemical reactions. We also extended the concept of DNA-mediated reaction to other nanoscale templates.
- (b) Studied the thermal and chemical stability of DNA origami template. The result shows that the DNA nanostructures can be potentially used in very harsh chemical environments.
- (c) Studied the effect of DNA origami template on the growth of self-assembled monolayer (SAM) structure. We developed a method to produce nanoscale patterns on SAM.
- (d) Studied the molecular imprinting of DNA origami structure using polymer substrates. Developed a high-resolution pattern transfer approach to pattern polymer surfaces.
- (e) Evaluated precursors for solution deposition of CdE (E = S, Se, and Te) semiconductors onto a DNA template.
- (f) Studied the wettability of graphitic carbon materials and its impact on the interaction between graphitic substrate and DNA nanostructures.

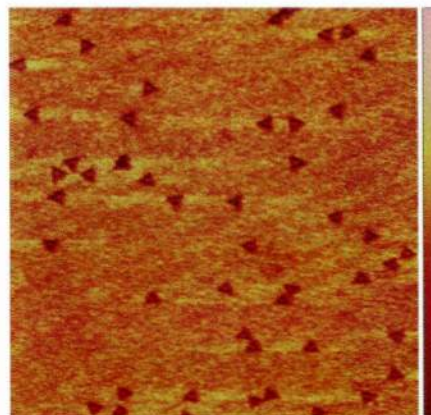
#### 4. Expanded Accomplishments

*(a) Mechanistic study of water-adsorption near a DNA templates and its impact on local chemical reactivity.*

Using the flow reactor we built last year, we have carried out a detailed kinetic study of DNA-mediated HF etching of SiO<sub>2</sub>. In this reaction, DNA locally enhances the etching of SiO<sub>2</sub> by promoting the adsorption of water. We have measured the detailed kinetic behavior of HF etching rate as a function of various reaction conditions, including vapor pressure of water and reaction temperature. These result provides the first insight into the absorptive properties of DNA nanostructure. (**Figure 1**).

*(b) Studied the stability of DNA nanostructure under a wide range of chemical environments.*

Many bottom-up fabrications, including those proposed here, involve very harsh processing conditions such as high temperatures and corrosive chemicals. However, DNA is a soft, chemically labile material that has limited thermal and chemical stability. Due to these reasons, the success of a DNA-mediated bottom-up fabrication is often limited and constrained by the stability of DNA nanostructures themselves. Therefore, understanding their structural stability under various chemical and physical environments is critical to the advance of this field of research. However, a systematic understanding of the stability of DNA nanostructure is currently lacking.



**Figure 1.** Negative-tone triangle patterns produced by using a DNA triangle template using our new CVD setup. Image size: 3  $\mu\text{m}$  x 3  $\mu\text{m}$ . Color scale represents 5 nm.

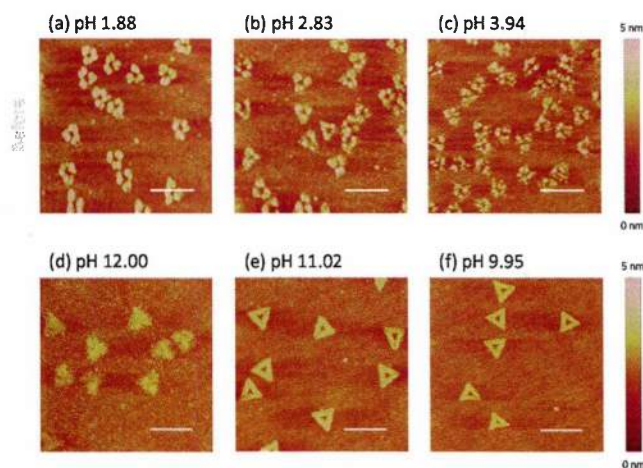


To prepare for our future effort in both gas phase and solution phase deposition reactions, we have conducted a study on the structural stability of DNA nanostructures deposited on a silicon wafer under a wide range of chemical and physical processing conditions, including thermal annealing, washing with organic and aqueous solvents, and UV/O<sub>3</sub> treatment. These processing conditions are chosen for their relevance to DNA-based bottom-up nanofabrications, including metallization of DNA nanostructures, DNA-mediated etching and chemical vapor deposition, and DNA-templated assembly of inorganic nanocrystals. Our result shows that DNA nanostructures, once deposited onto a silicon substrate, are surprisingly stable and survive very harsh treatments, including thermal annealing to 300 °C for 10 min, washing with various organic and aqueous solvents, very high pH, and brief UV/O<sub>3</sub> treatment. As an example, **Figure 2** shows the effect of pH on the structural stability of DNA origami deposited on a silicon wafer. The result suggests that the application window of DNA nanostructure is much wider than previously thought.

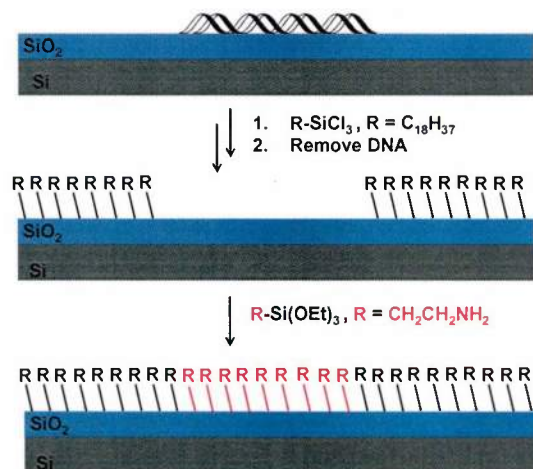
This study was initiated during the first year of the support. In this year, we have finished this study and published the results (see **Productivity** section).

*(c) DNA-mediated patterning of SAM.*

Forming SAM is a widely used approach to control and modify the surface properties, such as wetting, adhesion, surface potential, and surface chemistry. For this reason, SAMs have found a wide range of applications including patterning organic solids, molecular electronics, chemical and biological sensing, biomolecule immobilization, and nanofabrication. Many of these applications require nanoscale patterning of single component and/or mixed SAMs. We have used DNA nanostructures as a masking template to pattern SAM. We show that DNA nanostructures can block the diffusion of reagents to react with the substrate, resulting in a faithful pattern transfer to the SAM.



**Figure 2.** Effect of pH on DNA nanostructures. AFM images of DNA origami triangles immersed in (a) pH 1.88, (b) pH 2.83, (c) pH 3.94, (d) pH 12.00, (e) pH 11.02, and (f) pH 9.95 solutions for 10 seconds. Scale bars: 250 nm.

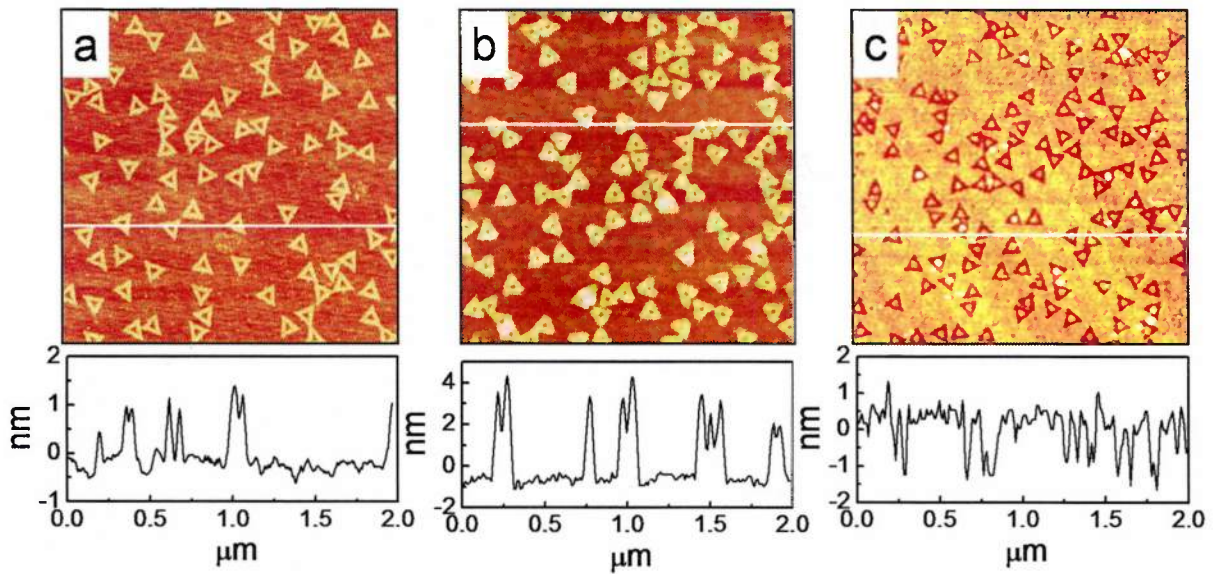


**Figure 3.** Patterning mixed silane SAMs using a DNA template. DNA nanostructures are assembled on a substrate and exposed to ODTCS vapor followed by removal of DNA, resulting in negative tone patterns in the ODTCS SAM. The patterned SAM is then exposed to 3-aminopropyl triethoxy silane (APTES) vapor, resulting in a patterned mixed SAMs.

**Figure 3** outlines the strategy we took to pattern silane SAM with DNA templates. Our approach relies on the vapor phase deposition of silane precursor onto a Si substrate that has a thin layer of native SiO<sub>2</sub> (Si/SiO<sub>2</sub> substrate). Briefly, DNA nanostructures were assembled on the Si/SiO<sub>2</sub> substrate and placed inside a glass container. The pressure inside the container was reduced to vaporize octadecyl trichlorosilane (ODTCS). The ODTCS vapor deposited on and around the DNA on the Si/SiO<sub>2</sub> substrate. On sonication in deionized water, the DNA nanostructures fell off the substrate resulting in negative tone patterns of ODTCS monolayers on the Si/SiO<sub>2</sub> substrate. The patterned SAM can be backfilled with a different silane to produce a mixed SAM (see below).

**Figure 4a** shows the AFM image and the cross section of triangular DNA nanostructures assembled on the Si/SiO<sub>2</sub> substrate. After exposing the Si/SiO<sub>2</sub> substrate containing DNA nanostructures to ODTCS vapor, the apparent height of the DNA nanostructure increased from *ca.* 1.5 nm to *ca.* 4.0 nm, suggesting that the silane deposited on the SiO<sub>2</sub> surface as well as on the DNA nanostructures (**Figure 4b**). After a brief sonication in deionized water, the DNA nanostructures readily fell off resulting in negative tone triangular patterns that are *ca.* 2 nm deep. The depth of the trenches is similar to that of the thickness of ODTCS SAM, suggesting that the bottom of the trenches is likely exposed SiO<sub>2</sub> surface (**Figure 4c**).

The above observations suggest that the DNA nanostructures are capable of blocking the diffusion and/or reaction of ODTCS molecules to the underlying SiO<sub>2</sub> surface. It is commonly accepted that the DNA nanostructures are anchored to the SiO<sub>2</sub> surface through electrostatic interaction mediated by Mg<sup>2+</sup>. In contrast, ODTCS is capable of forming covalent bond with the SiO<sub>2</sub> surface. Given these considerations, it is not entirely surprising that the DNA nanostructures can be easily removed by sonication without damaging the ODTCS SAM.

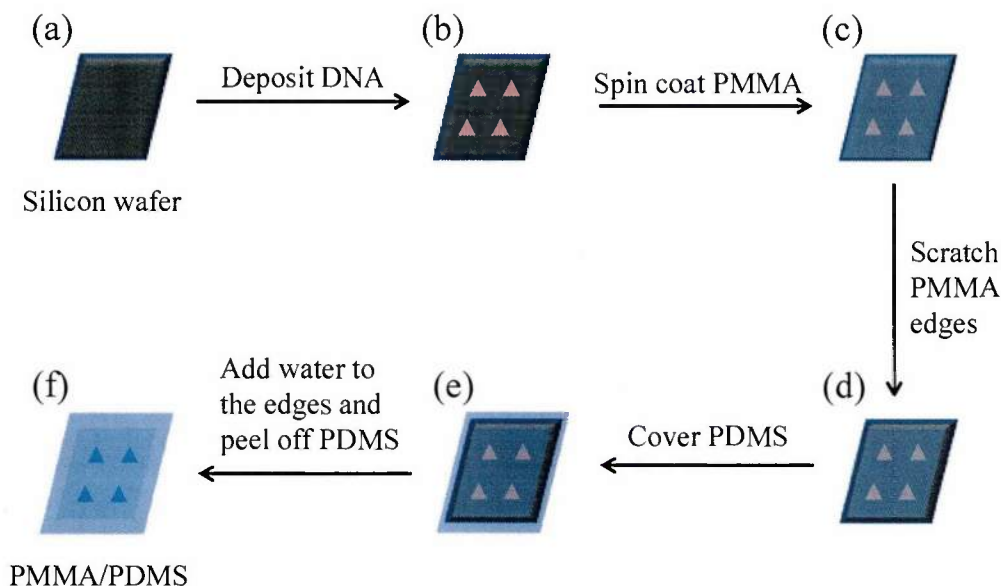


**Figure 4.** AFM images and cross sections of (a) DNA nanostructures assembled on a Si substrate. (b) Sample (a) after exposure to ODTCS. (c) Sample (b) after sonication in DI water to remove DNA. The white line indicates the line of cross section.

*(d) Molecular imprinting using DNA nanostructure templates.*

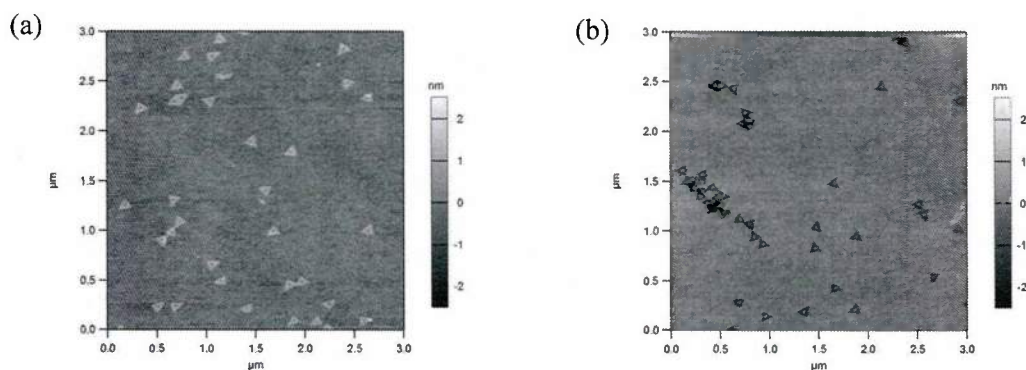
Soft lithography uses polymeric stamps with certain features to transfer the pattern for printing, modeling, phase-shifting edge lithography, and nanoskiving. To achieve nanoscale patterns, masks with nanoscale patterns are required. Electron-beam lithography has been applied to generate nanoscale patterns. However, this method is expensive and not generally accessible. We recently discovered that DNA nanostructure can serve as a promising template for nanoimprint lithography (Figure 5).





**Figure 5.** Molecular imprinting of DNA nanostructure into polymer substrates.

DNA triangles (**Figure 6a**) were firstly tested in the pattern transfer. AFM analysis showed that the negative pattern of DNA triangle with high fidelity appeared on the PMMA (**Figure 6b**). The width and the depth of the trench in the negative pattern were consistent with the dimension of DNA triangle. After the transfer, the density of DNA triangles decreased as the water weakened the interaction of DNA and the substrate and partially dissociated the DNA templates. We are currently extending this work to other types of DNA templates and prepare a manuscript for publication.



**Figure 6.** AFM images of (a) silica wafer with DNA triangles before the transfer, (b) the surface of PMMA after the transfer, and (c) silica wafer after the transfer.



*(e) Evaluated precursors for solution deposition of CdE (E=S, Se, and Te) semiconductors onto DNA.*

We have explored solution chemistry as an alternative to gas phase CVD to deposit inorganic materials onto a DNA template. Compared to CVD, solution phase chemistry could access a wider range of materials. CdE are important semiconductors with wide (E=S) and medium (E = Se, Te) bandgap and are useful in electronics and energy conversion. However, the synthesis of these materials typically involve harsh chemical environments. Our effort has been focused on identify new precursors and reaction conditions that are compatible with DNA template.

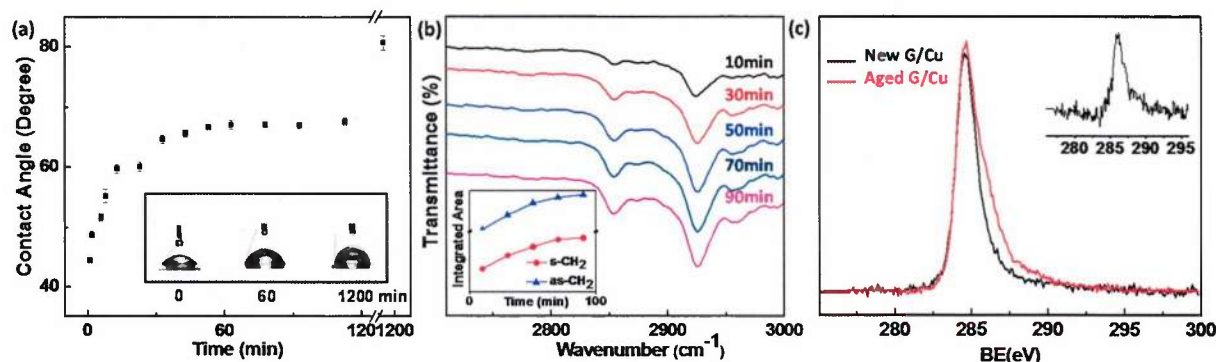
We have studied the solution structure of cadmium carboxylate using diffusion-ordered spectroscopy (DOSY). We found that the molecular weights of cadmium complexes highly depend on the solvent; the complexes are polymeric in toluene but break up in the presence of polar solvents or coordinating ligands. These information is critical to the selection of reaction conditions for solution deposition of semiconducting CdE materials. Part of the work was recently published in *Chem. Communication*.

The synthesis of high quality CdE nanocrystal is typically carried out at high temperature ( $>300^{\circ}\text{C}$ ), which is incompatible with DNA nanostructures. To explore low temperature chemistries that can be used with DNA templates, we have studied the effect of alkylamine on the kinetics of the synthesis of CdSe nanocrystals in solution. Alkylamine is known to accelerate nucleation of CdE nanocrystals but the mechanism is not known. Our result shows that alkylamine lowers the reactivity of precursors by binding to  $\text{Cd}^{2+}$ . Despite the decrease of reactivity, we found that alkylamine prohibits homogeneous nucleation by decreasing oversaturation and as a result, should facilitate heterogeneous nucleation of CdE on DNA nanostructure templates. Part of this work was recently published in *J. Am. Chem. Soc.*

*(f) Wettability of graphitic surface and its effect on the deposition of DNA nanostructure onto graphene and graphite.*

In our preliminary work, we have exclusively used silicon wafer as the supporting substrate for DNA. However, one major disadvantage of silicon wafer is its hydrophilic nature, which makes it highly active toward CVD reactions. This property makes it difficult to improve the spatial selectivity of the DNA-mediated CVD.

Graphitic surface is ideal for DNA-mediated CVD because it is known to be inert toward CVD. This fact makes it possible to achieve high spatial selectivity of the material deposition. However, graphitic surface is known to be hydrophobic and resist adsorption of double-stranded DNA nanostructures. We have investigated the wettability of graphitic materials and to our surprise we discovered that a clean graphitic surface is in fact slightly *hydrophilic*! As shown in **Figure 7a**, we found that the water contact angle of a freshly prepared graphene sample is around 45°, significantly lower than the generally accepted value of 85 – 90°. Detailed investigation showed



**Figure 7.** (a) Temporal evolution of the WCA measured on a graphene/copper sample. The sample was taken out of the CVD chamber at time 0. The three photographs show the water drops captured at 1 min, 60 min, and 1200 min. (b) ATR-FTIR spectrum of a graphene/copper sample. The spectra were shift vertically for clarity. The sample was taken out of the CVD chamber at time 0. The inset shows the integrated peak area vs time for the peaks at 2930  $\text{cm}^{-1}$  (asymmetric  $\text{CH}_2$  stretching, blue) and 2850  $\text{cm}^{-1}$  (symmetric  $\text{CH}_2$  stretching, red). (c) Carbon 1s XPS peak of an as-prepared graphene/copper sample and the same sample after exposed to air for 2 weeks. Inset: difference between new and aged Cu/G sample, BE: binding energy. Adapted from *Nature Mater.*, **2013**, 12, 925-931 with permission, copyright Nature Publishing Group.

that the water contact angle increases with increasing air exposure. Infrared spectroscopy and X-ray photoelectron spectroscopy showed that the change of wettability is linked to the adsorption of airborne hydrocarbon (**Figure 7b, c**). We therefore concluded that the previously observed hydrophobicity is due to airborne contamination of hydrocarbon.

This result overturned the long-held (> 70 years) view that graphitic surfaces are hydrophobic and will have significant impact to understanding their other interfacial properties, such as biofouling, adhesion, friction and electrochemistry. Part of this result was recently published in four peer reviewed articles in *Nature Materials*, *ACS Nano*, *Carbon*, and *Langmuir* and have received wide spread media attention.

Our ongoing work focuses on manipulating the wettability of graphene and graphite to enable the deposition of DNA nanostructures and from which to carry out CVD and solution deposition of inorganic materials.

## 7 Technology Transfer

A patent disclosure was filed.

## 8 Foreign Collaborators and Support of Foreign Nations (no limit)

N/A

## 9 Productivity (all resulted from research funded by this award)

### A. Refereed Journal Articles (\*: corresponding author, \_: undergraduate student):

21. Zhou, F.; Sun, W.; Ricardo, K.; Shen, J.; Yin, P.; Liu, H.\* “Programmable-shaped Carbon Nanostructure from Shape-conserving Carbonization of DNA” *ACS Nano*, **2015**, In review
20. Li, Z.; Kozbial, A.; Nioradze, N.; Parobek, D.; Shenoy, G. J.; Salim, M.; Amemiya, S., Li, L.\*; **Liu, H.\*** “Water protects graphitic surface from airborne hydrocarbon contamination” *ACS Nano*, In press.
19. Surwade, S.; Zhou, F.; Li, Z.; Powell, A.; O'Donnell, C.; Liu, H.\* “Nanoscale Patterning of Self-assembled Monolayers using DNA Nanostructure Templates” *Chem Comm.*, **2015**, *in press*
18. Kozbial, A.; Gong, X.; Liu, H.; Li, L.\* “Understanding the intrinsic water wettability of molybdenum disulfide (MoS<sub>2</sub>)” *Langmuir*, **2015**, *31*, 8429.
17. Hui, L.; Auletta, J. T.; Huang Z.; Chen X.; Xia F.; Yang S.; Liu H.; Yang L.\* “Surface Disinfection Enabled by a Layer-by-Layer Thin Film of Polyelectrolyte-Stabilized Reduced Graphene Oxide upon Solar Near-Infrared Irradiation” *ACS Appl. Mater. Inter.* **2015**, *7*, 10511-10517.
16. Parobek, D.; Liu, H.\* “Wettability of graphene” *2D Mater.* **2015**, *2*, 032001
15. Zhou, F.; Michael, B. C.; Surwade, S.; Ricardo, K. B.; Zhao, S.; Liu, H.\* “Mechanistic Study of the Nanoscale Negative-tone Pattern Transfer from DNA Nanostructures to SiO<sub>2</sub>” *Chem. Mater.* **2015**, *27*, 1692-1698
14. Zhao, S.\*; Liu, H.\* “Bottom-up nanofabrication through catalyzed vapor phase HF etching of SiO<sub>2</sub>” *Nanotechnology*. **2015**, *26*, 015301
13. Li, Z.; Zhou, F.; Parobek, D.; Shenoy, G. J.; Muldoon, P., Liu, H.\* “Copper substrate as a catalyst for the oxidation of chemical vapor deposition-grown graphene” *J. Solid State Chem.* **2015**, *224*, 14. DOI: 10.1016/j.jssc.2014.02.021
12. Kim, H.; Surwade, S. P.; Powell, A.; O'Donnell, C.; Liu, H.\* “Stability of DNA origami nanostructure under diverse chemical environments” *Chem. Mater.*, **2014**, *26*, 5265-5273
11. Hui, L.; Piao, J.; Auletta J.; Hu, K.; Zhu, Y.; Meyer, T.; Liu, H.\*; Yang, L.\* “Availability of the Basal planes of graphene oxide determines whether it is antibacterial” *ACS Appl. Mater. Interfaces*. **2014**, *6*, 13183-13190.

10. Kozbial, A.; Li, Z.; Conaway, C.; McGinley, R.; Dhingra, S.; Vahdat, V.; Zhou, F.; D'Urso, B.; Liu, H.\*; Li, L.\* “Study on the surface energy of graphene by contact angle measurement” *Langmuir*, **2014**, 30, 8598. DOI: 10.1021/la5018328
9. Novak, M.; Surwade, S. P.; Prokop, J.; Bolotin, K.; Hone, J.; Brus, L.; Nuckolls, C.\*; Liu, H.\* “Visualizing individual carbon nanotubes with optical microscopy”. *J. Am. Chem. Soc.* **2014**, 136, 8536
8. Garcia-Rodriguez, R; Liu, H.\* “A nuclear magnetic resonance study of the binding of trimethylphosphine selenide to cadmium oleate” *J. Phys. Chem. A* **2014**, 118, 7314. DOI: 10.1021/jp411681f
7. Garcia-Rodriguez, R; Liu, H.\* “Mechanistic insights into the role of alkylamine in the synthesis of CdSe nanocrystals” *J. Am. Chem. Soc.*, **2014**, 136, 1968-1975
6. Xiang, G.-L.; Long, Y.; He, J.; Xu, B.; Liu, H.\*; Wang, X.\* “Unusual Enrichment and Assembly of TiO<sub>2</sub> Nanocrystals at Water/Hydrophobic Interfaces in a Pure Inorganic Phase” *Langmuir*, **2014**, 30, 617-623.
5. Kozbial, A.; Li, Z.; Sun, J.; Gong, X.; Zhou, F.; Wang, Y.; Xu H.; Liu, H.\*; Li, L.\* “Understanding the intrinsic water wettability of graphite.” *Carbon*, **2014**, 74, 218
4. Ricardo, K. B.; Sendecki, A.; Liu, H.\* “Surfactant-free exfoliation of graphite in aqueous solutions” *Chem. Comm.* **2014**, 50, 2751-2754
3. Li, Z.; Wang, Y.; Kozbial, A.; McGinley, R.; Ireland, P.; Morganstein, B.; Kunkel, A.; Surwade, S. P. Li, L. and Liu, H. “Effect of airborne contaminants on the wettability of supported graphene and graphite” *Nature Mater.*, **2013**, 12, 925-931
2. Zhou, F.; Li, Z.; Shenoy, G. J.; Lei, L.; Liu, H. “Enhanced Room-Temperature Corrosion of Copper in the Presence of Graphene” *ACS Nano*, **2013**, 7, 6939 - 6947
1. Garcia-Rodriguez, R; Liu, H. “Solution structure of cadmium carboxylate and its implication to the synthesis of cadmium chalcogenide nanocrystals” *Chem Comm.*, **2013**, 49, 7857-7859

## **B. Non-Refereed Significant Publications**

Ricardo, K. B.; Liu, H. “Surfactant free, aqueous graphene dispersion and method of production of surfactant-free aqueous graphene dispersion” US Provisional patent application. S.N.: 61652625

## **C. Books and Chapters**

None



## **D. Technical Report**

1. Liu, H. (Department of Chemistry, University of Pittsburgh). "DNA-Based Molecular Scale Nanofabrication" Final progress report. June 1st, 2014 to May 15<sup>th</sup>, 2015, Contract N000141310575 (Office of Naval Research).
2. Liu, H. (Department of Chemistry, University of Pittsburgh). "DNA-Based Molecular Scale Nanofabrication" Interim report. May 14<sup>th</sup>, 2013 to May 31<sup>st</sup>, 2014, Contract N000141310575 (Office of Naval Research).

## **E. Workshops, Conferences, Invited Talks**

23. "Intrinsic wettability of graphene and graphite" Graphene Week, June 2015, Manchester, UK
22. "Intrinsic wettability of graphene and graphite" Department of Chemistry, Beijing University of Technology, June 2015, invited
21. "Intrinsic wettability of graphene and graphite" Department of Chemistry, Nanjing University of Technology, June 2015, invited
20. "Intrinsic wettability of graphene and graphite" Department of Chemistry, University of Science and Technology of China, June 2015, invited
19. "Intrinsic wettability of graphene and graphite" Department of Chemistry, University of Connecticut. May 2015, invited.
18. "DNA-based nanofabrication under extreme chemical environments" FNano 2015, Snowbird, UT, April, 2015, Invited.
17. "A general mechanism for the synthesis of group IV-VI and II-VI nanocrystals" MRS Spring 2015 meeting, San Francisco, April 2015
16. "Intrinsic wettability of graphene and graphite" Department of NanoEngineering, University of California, San Diego. April 2015, invited.
15. "Intrinsic wettability of graphene and graphite" Department of Chemistry, Washington University in St. Louis. Feb 2015, invited.
14. "DNA mediated surface reactions" ACS National Meeting, San Francisco, August, 2014
13. "Mechanistic insight into the effect of alkylamine on the synthesis of CdSe nanocrystals" ACS National Meeting, San Francisco, August, 2014
12. "Mechanistic insight into the effect of alkylamine on the synthesis of CdSe nanocrystals" Colloidal Nanocrystals GRC, Smithfield, RI, July, 2014
11. "DNA nanostructures meet nanofabrication" Nanostructure Fabrication GRC, Biddeford, ME, July, 2014

10. "Intrinsic wettability of graphene" Chemistry and Physics of Graphitic Carbon Materials GRC, Lewiston, ME, June 2014
9. "On the intrinsic wettability of graphene and graphite" Graphene Week 2014, Gothenburg, Sweden, June 2014
8. "On the intrinsic wettability of graphene and graphite" New Diamond and NanoCarbon Conference, Chicago, May 2014
7. "DNA nanostructures meet nanofabrication" FNANO14, Snow bird, UT, April, 2014. Poster
6. "On the intrinsic wettability of graphene" ACS National Meeting, Indianapolis, IN, 09/2013
5. "Solution structure of cadmium carboxylate probed by DOSY" Gordon Conference on Clusters, Nanocrystals, and Nanostructures, Mount Holyoke College, 08/2013
4. "Intrinsic wettability of graphene" UK-China Summer School Tribology & Surface Engineering, Qingdao, China. July, 2013. Invited talk.
3. "Nanoscale patterning and growth of inorganic oxides" GRC on self-assembly and supramolecular chemistry, Les Diablerets, Switzerland, May, 2013. Poster
2. "Synthesis of custom shaped DNA-inorganic hybrid materials" European Materials Research Society Meeting, Strasburg, France, 05/2013. Invited oral presentation
1. "Intrinsic wettability of graphene" 40<sup>th</sup> International Conference on Metallurgical Coatings and Thin Films, San Diego, 05/2013. Invited oral presentation

#### **F. Patens**

N/A

#### **G. Awards/Honors**

N/A

#### **10 Award Participation:**

Number of Principal Investigators: 1, male non-minority

Number of Undergraduate Students: 2 (research support only, no salary support).

Number of Graduate Students: 4, including 1 female, 1 female minority, and 2 male non-minority.

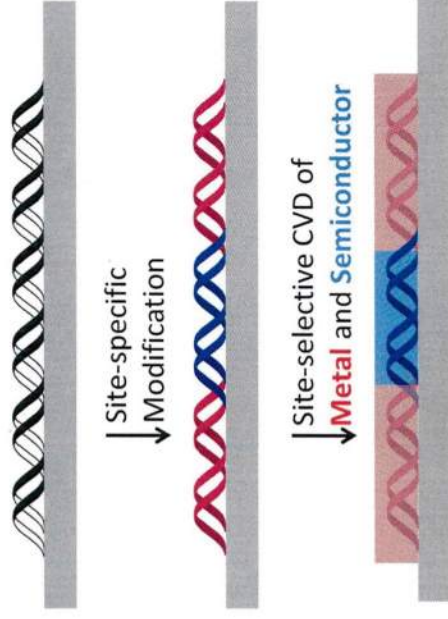
Number of Post Docs (male non-minority, female non-minority, male minority, or female minority): 1 male non-minority (research support only, no salary support).

#### **12 Quad chart**

Attached as a separate file.

# DNA-Based Molecular Scale Nanofabrication

## N000141310575



### OBJECTIVE:

- To provide a fundamental understanding of the effect of DNA on vapor and solution phase reactions.
- To develop DNA-templated reactions for the deposition and heterogeneous integration of inorganic materials.
- To develop DNA-based nanofabrication for high resolution patterning of inorganic/organic substrates

### APPROACH:

- Carry out mechanism study of DNA-mediated CVD of inorganic oxides.
- Develop new chemistries that will selectively deposit semiconductors and metals onto a DNA template.
- Explore DNA modifications to achieve site specific and materials specific deposition.

### ACCOMPLISHMENTS:

- Identified reaction mechanism of DNA-mediated etching and deposition reactions.
- Developed new lithography approaches to pattern self-assembled monolayers and polymer substrates
- 21 peer-reviewed journal articles/submitted manuscripts, 23 conference presentations/invited talks.

### PERFORMERS:

- PI: Haitao Liu (male non-minority)
- Graduate students: Karen B. Ricardo (female minority), Hyo Jeong Kim (female), Feng Zhou, and Zhiting Li.

### IMPACT/TRANSITIONS:

- Could lead to a radically new approaches of nanoscale device fabrication.
- Could enable the production of low-power, light-weight electronic and optoelectronic components that are essential to reducing weight load and enhancing survival of Marines and SEALs.